ENERGY PERFORMANCE LEVEL IDENTIFICATION OF AN PUBLIC TRANSPORT CAR FLEET

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Abstract: Knowing the level of energy efficiency is essential for substantiating investment decisions, operation and maintenance of energy consuming equipment and machines. Urban public transport is an important consumer of energy and, at the same time, an important source of pollution of the urban environment with greenhouse gases and micro particles. The present paper is aimed to identify the level of the energy performance of a public transport car fleet, having buses equipped with Diesel engines. The analysis methodology and the mathematical model used are applicable to other similar structures. The obtained results are valid for the analyzed car fleet, highlighting the values of the energy performance indicators, on the whole, by bus categories and for each bus from the park component. Based on the results obtained within the energy audit, comparisons are made for the level of energy performance with similar consumers, and feasible measures to improve energy efficiency are identified.

Keywords: energy performance, car fleet, indicators, public transport, energy audit.

1. INTRODUCTION

Transport ranks first among economic sectors in the EU, in terms of energy consumption, having in 2017 a share of 30.8% of total consumption [1]. At the level of Romania, the share in the total energy consumption of the transport sector is also important (about 25%), and at the level of municipalities this sector has the highest share [2], public transport being an important component of the transport sector in urban areas. Considering the fact that the transport sector is identified with a share of about 20% in the structure of greenhouse gas emissions (GGE) [3], it is obvious the importance of the concerns regarding the energetic and technological means of efficiency for this sector. The regulations in force [4,5] and those for the next cycle [6,7] have mobilizing targets in this regard. For example, [6,7] sets a target of a 32.5% reduction in primary energy consumption at EU level, in 2030, compared to 2007 forecasts, and the reduction of GGE by at least 40% by 2030 compared to 1990 levels. The main national regulations in this field [8,9,10] are well connected to the EU regulations and anchored with the reality in Romania, the fixed targets being, equally, mobilizing and realistic. In the public transport subsector, in order to increase energy efficiency, action is taken, mainly, in the following directions [2,9]:

- Development of multimodal transport;
- Optimizing the ratio between fossil fuels and alternative fuels;
- Increasing the quality, speed and efficiency of parking;
- Efficient and ecological means of transport (low consumption, recovery, electric).

To identify the level of efficiency of public transport means (PTM), and the means to improve it, the established method is energy audit (EA). The EA elaboration methodology is well known and widely applied [11-20].

This paper presents the results obtained in the elaboration of the EA of a public transport fleet (PTF), equipped with PTM type buses with Diesel engines. Besides the concrete results obtained, we consider the paper useful from a methodological point of view, in the sense that, in the accessible specialized literature [11-20] one not identifying the methodology and the complete mathematical model (MM) for the energy balance (EB) of the object subject to EA (buses with Diesel engines ≡ BDE). Based on the general principles and equations of EB, we proceeded to solve the problem by elaborating the necessary equations for completing the MM of EB of the Diesel engine and presenting the MM of EB and the EA methodology of BDE in a complete, unitary form. The EA methodology and the EB model of the BDE, presented in this paper, are applicable in other similar cases, and the concrete results obtained are characteristic of BDE, PTF and the public transport operator (PTO) subject to analysis.

2. THE CONTOUR OF THE EA

The PTO at which the EA was performed is "Oradea Local public Transport" (OTL), having as object of activity the public transport service in Oradea municipality (PTS-OM). Both in Bihor County and in the Oradea metropolitan area, the motorization rate has been continuously increasing in the last five years. At the end of 2015, a number of 97,226 vehicles were registered in the municipal registers, which mean 436 motor vehicles per 1000 inhabitants [7]. Currently, PTS-OM consists of seven tram routes and twenty routes for local buses, covering the main transport routes of the OM and metropolitan area. The recent evolution of the fundamental performance indicators (FPI) of PTS-OM is summarized in fig.1. Thermal energy audit (TEA) refers to the public transport fleet (TEA-PTF).

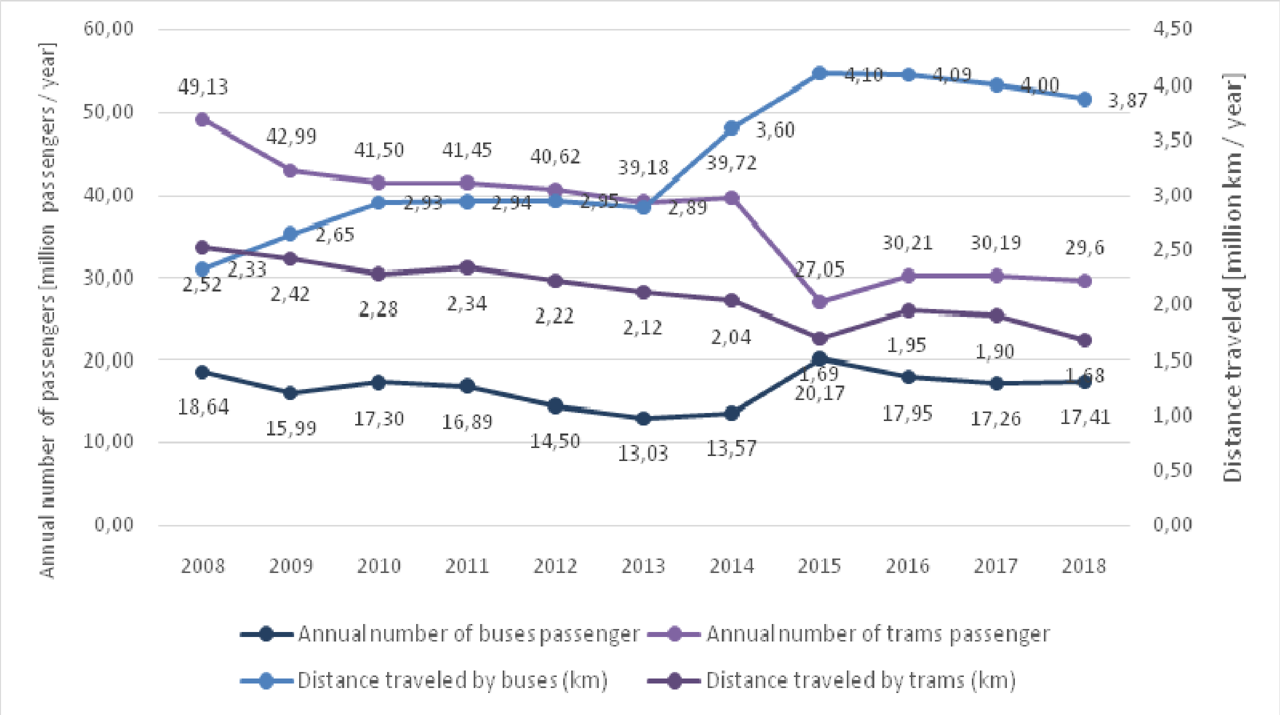

Fig. 1. The performance of the public transport network of Oradea

In order to achieve TEA, direct measurements were performed on 6 of the 92 buses powered by Diesel engines (BDE). Also, the information taken from the OTL database was used, for the period [2016 - 2019]. The measurements were performed under normal operating conditions, which presuppose the existence of all specific regimes: starting, acceleration, stabilized load, braking, idling. Along with the registration of the operating quantities, the number of passengers was also noted, in order to calculate the efficiency indicators (energy, economic) of each audited BDE and to rank, on this basis, the BDE from the beneficiary's endowment. The thermal energy balance (TEB) sub-contour is represented by each BDE for which measurements were performed, and the contour consists of the whole BDE analyzed.

BDE's fleet consists of a total of 92 BDEs of the following brands:

- VOLVO, medium (14 pcs) and large (12 pcs);
- MERCEDES, medium (29 pcs);
- MAN, medium (11 pcs) and large (3 pcs);
- SOLARIS, large (10 pcs);
- ISUZU, small (7 pcs);
- KARSAN, small (5 pcs);
- IVECO, small (1 pc).

In 2018 they did not work or worked very little: 11 BDE - MAN, 2 BDE - MERCEDES and BDE - ROCAR. These will not be included in the TEA. Therefore, TEA refers to the 80 BDEs that fully operated in 2018. The complete characteristics of the BDE in the fleet used by OTL for public transport are summarized in [21].

The magnitude of the service performed is shown by specific indicators: number of trips (Nc), distance traveled (D), passengers transported (N_{CL}). During 2018, the values of these indicators were:

$D = 1.68$ million km;

$N_{CL} = 29.6$ million passengers;

The average value for one day of the mentioned indicators is:

$d = 4602.7$ km / day;

$n_{CL} = 81095.9$ passengers / day.

For the purpose pursued by the beneficiary in this TEA - in line with European practice [22], the adopted unit of reference is "passenger carried", "distance traveled" and "passenger x distance".

The loading level of BDEs subject to TEA was the normal one for the service provided by OTL and is materialized by the number of passengers transported on the fixed route, a number recorded in the tables given in [21].

The measuring devices used to perform the measurements are:

- Fluke Ti20 thermometer;
- Gas analyzer type TESTO 350 CU.

3. THE MATHEMATICAL MODEL OF TEA ELABORATED

For the most part, BDE is a consumer of thermomechanical drive, the main useful effect being the movement of BDE with passengers. In addition, there are some useful (side) effects, which for BDE analyzed are: air conditioning, lighting and "adblue" (reduction of NO and NO_2 flue gases).

3.1. The general equation of TEB

The TEB diagram of the analyzed BDE is shown in fig.2.

where:

W_a - absorbed energy;
ΔW_{ga} - energy (heat) dissipated by flue gases;
ΔW_{nm} - energy losses (heat) through mechanical burns (soot from flue gases);
ΔW_{rc} - energy losses (heat) through radiation and convection in the environment;
ΔW_{ar} - energy (heat) discharged through the engine coolant;
ΔW_{mec} - mechanical energy losses in moving BDE;
W_{CPT} - BDE's own technological consumption, for utilities (lighting, adblue, air conditioning);
W_u - useful energy.

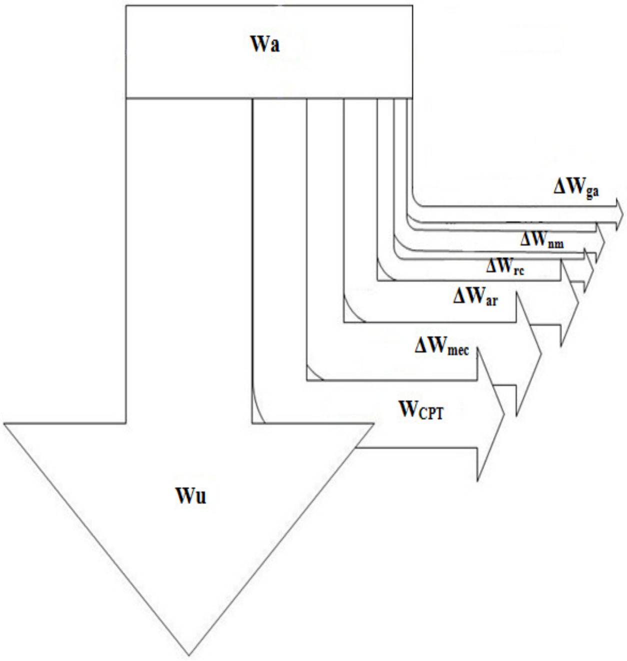

Fig.2. TEB diagram for a stabilized BDE

Therefore the BTE equation for BDE, in stabilized regime can be written:

$$W_a = W_u + \Sigma W_p + W_{CPT} \quad (1)$$

where:

ΣW_p – total energy losses

3.2. The calculation method of the components from the TBE equation

The calculation relations of the BTE components are written to obtain their values in [kJ].

3.2.1. The energy entered

The fuel used by the Diesel engine in the BDE construction is the main energy agent through which the energy enters the contour. According to [11 - 17], in this case, it can be written:

$$W_a = Q_{cc} + Q_{fc} + Q_{aa} \quad (2)$$

where:

Q_{cc} - chemical heat of the consumed fuel;
Q_{fc} - physical heat of the consumed fuel;
Q_{aa} - the physical heat of the combustion air.

Evaluations are made for a certain duration (τ), called the analysis duration. The calculation relations of the 3 components are [13, 17]:

$$Q_{cc} = B_c \cdot H_{ci} \quad (3)$$

$$Q_{fc} = Bc \cdot c_c \cdot \theta_c \quad (4)$$

$$Q_{aa} = D_a \cdot i_a \cdot \rho_a \cdot \tau \quad (5)$$

where:

B_c - the amount of fuel consumed during the analysis [kg];
H_{ci} - lower calorific value of the fuel [kJ/kg];
c_c - specific heat of the fuel [kJ/kg·°C];
θ_c - engine inlet temperature of fuel [°C];
D_a - combustion air flow [$m^3{}_N/h$];
i_a - enthalpy of combustion air [kJ/kg];
ρ_a - density of combustion air, at atmospheric pressure and temperature (p_{atm}, θ_{atm}) [$kg/m^3{}_N$];
τ - duration of analysis [hours].

For the fuel used (Diesel), the quantities included in the relations [3 ÷ 5], are calculated as follows [13,17]:

$$c_c = 1.7375 + 0.0025\ \theta_c \quad (6)$$

$$D_a = \lambda \cdot D_{at} \cdot B_c \quad (7)$$

where:

λ - excess air coefficient;
D_{at} - theoretical rate of the combustion air flow [m^3N/h].

3.2.2. Energy loses

a) Heat dissipated by flue gases

It has two components, one physical (Q_{fg}) and the other chemical (Q_{cg}) [13, 17]:

$$\Delta W_{ga} = Q_{fg} + Q_{cg} \quad (8)$$

$$Q_{fg} = V_{ga} \cdot i_g \quad (9)$$

$$Q_{cg} = 125.72 \cdot CO^{um} \cdot V_{ga} \quad (10)$$

where:

V_{ga} - total volume of flue gases [m^3N];
i_g - enthalpy of flue gases [kJ/m^3N];
CO_{um} - share of carbon monoxide in wet flue gases [%].

The quantities in the relations (8 ÷ 10) are calculated as follows [13,17]:

$$V_{ga} = B_c \cdot V_g = B_c(V_g^{US} + V_{H2O}) \quad (11)$$

$$CO^{um} = CO\frac{V_g^{US}}{V_g} \quad 12)$$

where:

V_g^{US} – the specific volume of dry flue gases [$m^3{}_N/kg$] [13];
V_{H2O} – the specific volume of water vapor [$m^3{}_N/kg$] [13];
CO – measured share of carbon monoxide in the flue gas [%].

b) Heat dissipated by mechanical burns

It is determined by the relation [13, 17]:

$$\Delta W_{nm} = 33.983 \cdot C_f \cdot V_{ga} \quad (13)$$

where:

C_f – the soot content of the flue gases [$g/m^3{}_N$].

In the case of BDE for the calculation of the size (C_f) the result of the Periodical Technical Inspection (PTI) test is used from which the opacity value (O_p) is obtained - quantity that reflects the concentration of carbon particles in the flue gases (exhaust gases). The higher the number of particles, the higher the opacity, and the higher the degree of pollution. The opacity value is expressed in [%] on a scale from 1 to 100 (darkness level), as well as in m^{-1} - representing the light absorption coefficient. There is a correspondence between the two modes of expression [23, 24], for example:

[%]	0	64	71	99
[m^{-1}]	0	2.5	3	11.31

The ITP test performed on BDE - OTL gives O_p in [m^{-1}]. For the calculation of C_f, we will use the conversion graph from [13, 17] and the correction relation as a function of temperature:

$$C_f = C_{fm}\frac{273+\theta_{ga}}{273} \qquad [g/m^3_N] \qquad (14)$$

where:

C_{fm} – the measured value of C_f, obtained by converting hartrige units to [g/m^3], through the mentioned graph.

c) Energy losses through radiation and convection [13, 17]

$$\Delta W_{rc} = \alpha_{rc} \cdot A(\theta_m - \theta_a)\cdot\tau \qquad (15)$$

where:

α_{rc} – heat transfer coefficient by radiation and convection [$kW/m^2\cdot°C$];

A – the area of the surface through which heat is transmitted by radiation and convection from the engine to the environment [m^2];

θ_m – the average temperature of the surface through which heat is emitted [°C];

θ_a – ambient temperature [°C].

For the case (Diesel engine) analyzed, the heat transfer coefficient (α_{rc}) is calculated with the relation [13, 17]:

$$\alpha_{rc} = 1.16\,[4.9 + 5.6 \cdot 10^{-4}\,\theta_m] \qquad (16)$$

d) Energy discharged into the environment with the engine coolant

All BDEs covered by this TEA are antifreeze cooled in a closed circuit. The heat transferred from the engine to the antifreeze is evacuated to the environment by ventilating (cooling with air) the radiator. We will apply the relation:

$$\Delta W_{ar} = D_{ar} \cdot c_a(\theta_{ae} - \theta_{ai}) \cdot \tau \qquad (17)$$

where:

D_{ar} – cooling antifreeze flow rate [kg/h];

c_a – the specific heat of the antifreeze [$kJ/kg\cdot°C$];

(θ_{ae}, θ_{ai}) – antifreeze temperature at engine outlet (θ_{ae}) and at the engine inlet (θ_{ai}) [°C].

e) Mechanical energy losses in the moving BDE

To determine this component, the experimental method will be used. The energy consumption of the BDE will be measured in two operating phases:

- Static Idle operation (SI) of the BDE, inside the garage. BDE s switched on at the parking place and is allowed to operate, within a reasonable time (T_G). Fuel consumption is measured during the test interval (B_C^{GS}). On we calculate the energy absorbed during this interval (W_a^{GS}), applying relations (2÷7).
- BDE's Dynamic Idle (DI) operation on the regular running path. BDE will travel, without passengers, the same time interval (T_G). Fuel consumption is measured during the test interval (B_C^{GD}). On we calculate the energy absorbed during this interval (W_a^{GD}), applying relations (2÷7).

On we calculate the component ΔW_{mec} with the relation:

$$\Delta W_{mec} = W_a^{GD} - W_a^{GS} \qquad (18)$$

The total energy losses are calculated with the relation:

$$\Delta W_p = \Delta W_{ga} + \Delta W_{nm} + \Delta W_{rc} + \Delta W_{ar} + \Delta W_{mec} \qquad (19)$$

3.2.3. Useful energy and own technological consumption

a) Own technological consumption (OTC) of the energy for an BDE is calculated with one of the relations:

$$W_{CPT} = P_{med}^{UT} \cdot \tau \qquad (20)$$

$$W_{CPT} = P_{CPT} \cdot W_a$$

where:

P_{med}^{UT} – average power consumed by BDE utilities (lighting, adblue, air conditioning).

P_{CPT} – the multiannual share of OTC [u.r.].

For BDEs equipped with utility consumption metering, the value (W_{CPT}) can be obtained by summing, over the analysis period (τ) the components:

$$W_{CPT} = \sum_{\substack{i\,\epsilon\,\{UT\}\\ t=\tau}} W_i \qquad (21)$$

b) Useful energy (W_U) is in this case, energy used to transport passengers. It is obtained from relation (1):

$$W_U = W_a - (\sum W_p + W_{CPT}) \qquad (22)$$

3.3. Energy Performance Indicators (EPI)

For the BDE fleet, the evaluation of the following EPIs is suitable:

3.3.1 General EPI:

It is expressed in accordance with [12], as follows:

a) Gross energy efficiency

$$\eta_b = \frac{W_u + W_{CPT}}{W_a} \cdot 100\ [\%] \qquad (23)$$

b) Net energy efficiency

$$\eta_n = \frac{W_u}{W_a} \cdot 100\ [\%] \qquad (24)$$

c) Specific net energy consumption

$$c_n = \frac{Q_c}{W_u} \cdot 100[\%] \qquad (25)$$

where:

$$Q_c = Q_{cc} + Q_{fc} \qquad (26)$$

d) Degree of engine load

$$g_{IM} = \frac{P_{med}^M}{P_n^M} \qquad (27)$$

where:

P_{med}^M – average engine power (mechanical, shaft), over a continuous operating range;

P_n^M – rated engine power.

e) Energy intensity (I_w) and energy productivity (P_w)

$$I_w = \frac{Q_c}{V_{SP}} = \frac{1}{P_w} \qquad (28)$$

where:

V_{SP} – the value of the service provided [Euro].

3.3.2 Specific indicators:

Indicators are very important for public transport, including BDE [5,6,22] .

a) **Specific energy consumption (fuel)**:

$$c_s^w = \frac{Q_c}{D} \quad (29)$$

D – distance traveled [km];

b) **Specific "complex" energy consumption (fuel)**:

$$c_{sc}^w = \frac{Q_c}{D \cdot N_p} \quad (30)$$

Np - number of passengers carried over distance (D).

4. THE OBTAINED RESULTS

4.1. The results of measurements

In the documentation of TEA [21] these information are structured in two chapters (parts): information obtained from OTL databases and respectively, results from measurements made by the performer of TEA.

The OTL database contains significant information's, useful to elaborate the TEA. These data was taken based on records from years [2016 ÷ 2018] and the first 6 months of 2019 and structured into typified tables, with table head as it shown in table 1.

Table 1(typified). Input values to elaborate the TEA of BDE [extracted from OTL Database – 2016]

Side No.	Brand (bus type)	Traveled distance [km]		Consumption [liters]				OTC [liters]			
		Total buses	Total type	Rated		Effective		Heating	Cooling	AdBlue	Total
				Total BDE	Total type	Total BDE	Total type				
0	1	2	3	4	5	6	7	8	9	10	11
84	ISUZU NOVOCITI	99280.50		16572.82		19790.82		0.00	409.40	0.00	409.40
…	…	…	…	…	…	…	…	…	…	…	…

Results obtained from PTI test for 6 BDE are shown in [21]. Based on values from typified table [21], are calculated the values of multiannual share of own technological consumption (P_{CPT}), for 4 tested types of BDE and for the overall BDE. They are shown on table 2.

Table 2. Share of OTC by types of BDE

Type of BDE	P_{CPT} [%]
MERCEDES	6.5
VOLVO	3.8
SOLARIS	6.2
ISUZU	2.6
Overall BDE – OTL	6.5

In order to identify some values of some quantities from TEB model of BDE, direct measurements were performed on some samples, during [12.08 ÷ 04.09].2019.

For a more edifying evaluation, measurements were made on the samples with maximum specific consumptions, for the most important brands from the structure of the PTF of OTL, respectively: MERCEDES (2 pcs), VOLVO (2 pcs), SOLARIS (1 pc) and ISUZU (1 pc).

The obtained results are documented in tables 3 and 4. The results of analyzes regarding the content of the substances and other elements of characterization of the flue gases (exhaust) are presented in [21]. For each BDE, two analysis reports (AR) were placed - one for idle operation and the other for the operating speed in load. The results of the measurements performed with the thermal imaging camera are shown in [21]. For example fig. 3 shows the image obtained in the case of BDE no. 115.

Other calculation elements:

- Calorific value of the fuel used (diesel): 42.254 kJ/kg;
- Enthalpy of combustion air: 51.21 kJ/kg;
- Combustion air density: 1.293 kg/m^3_N;
- Theoretical combustion air flow: 11.078 m^3_N/kg·h;
- Specific antifreeze heat: 0.63 kJ/kg·°C;
- Antifreeze density: 1.05 kg/dm^3.

Table 3. Calculation items for TEB of BDE tested

Brand	Side No.	The cooling elements outer surface area of the engine [m^2]	Engine cooling antifreeze flow rate [thousand liters/h]	Idle fuel consumption [liters]		Test duration [h]		Flue gas composition	Excess air coefficient [in load]	The soot content The soot content [m^{-1}]
				Static (GS)	Dinamic (GD)	GS	GD			
MERCEDES	115	6.93	7	1.39	4.36	0.5	0.5	BA-115	4.56	3
	134	6.93	7	2.75	4.87	0.5	0.5	BA-134	4.68	3
VOLVO	146	7.33	6.5	3.09	4.6		0.5	BA-146	3.2	3
	76	7.74	6.5	1.09	4.94	0.5	0.58	BA-76	3.82	3
SOLARIS	150	8.64	6.5	1.62	4.49	0.5	0.53	BA-150	4.49	3
ISUZU	89	4.79	7	1.85	4.46	0.5	0.53	BA-89	5.91	3

Table 4. Results of measurements on BDE of PTO [load test]

Brand	Side No.	Temperatures [°C]								Route				Fuel [liters]	Test duration [h]
		Fuel	Burning air	Cooling water		Environment	Burning gas	Engine surface	Atmospheric	Line	No. of stations	Total distance [km]	No. average travelers		
				In	Out										
MERCEDES	115	29.3	29	53.2	72.9	30.3	91.3	60	29	14	25	12.3	16.4	5.67	0.75
	134	27.6	26	48.5	70.3	35	62.3	82.6	26	14	25	12.3	13.9	5.70	0.75
VOLVO	146	20.2	21.8	44.5	58.2	37.1	96.2	80	21.8	14	25	12.3	12.8	5.96	0.75
	76	31.3	25.2	44.1	78.2	46	60.3	104.5	25.2	512	13	15	14	6.55	0.43
SOLARIS	150	27.7	23.7	50	73	43.2	50.3	80	23.7	14	25	12.3	12.7	5.87	0.75
ISUZU	89	29	25	49	70	40	87.1	84	25	512	13	15	9	5.94	0.43

4.2. Results obtained regarding the real TEB

Based on mathematical model of technical characteristics and measurements the real TEB components of BDE are evaluated.

We provide a summary for this purpose. Details are presented in [21].

The values obtained for the calculation items (CI), with reference to the other five BDE at which complete measurements were performed, are summarized in Table 5.

The results obtained for the most important brands (for which complete measurements were performed) are shown in [21].

In order to exemplify, in table 6 are shown the results obtained in the case of Mercedes, and for the overall PTF of OTL, the results are presented in table 7.

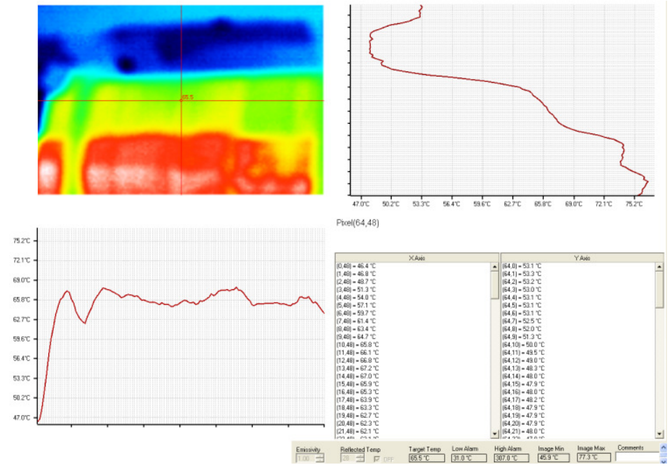

Fig. 3 – Thermal images of BDE no 115 engine.

Table 5. CI for TEA of BDE – OTL at which complete measurements were made

Side no. BDE CI	115	146	76	150	89
Q_{cc} [10^3 kJ]	206.03	216.57	238	213.3	215.84
c_c [kJ/kg·°C]	1.81	1.788	1.815	1.81	1.81
Q_{fc} [kJ]	258.6	185.1	320	253.1	268.1
D_a [m^3_N/h]	202.9	181.5	238.2	251.2	334.6
Q_{aa} [10^3 kJ]	10	8.96	6.76	12.43	9.53
V_g^{US} [m^3_N/kg]	28	32.5	30.3	38.3	17.4
V_{H2O} [m^3_N/kg]	0.88	1.02	0.96	1.2	0.55
V_g [m^3_N/kg]	28.88	33.52	31.26	39.5	17.95
V_{ga} [m^3_N]	140.9	171.6	176	199.5	91.7
CO^{um} [%]	9.7	7.8	16.5	13.6	28.2
i_g [kJ/m^3_N]	96.3	70.1	181.4	96.4	118.4
Q_{fg} [10^3 kJ]	13.6	12.03	31.9	19.2	10.8
Q_{cg} [10^3 kJ]	1.77	1.72	3.76	3.5	3.34
c_f [g/m^3_N]	0.48	0.45	0.57	0.48	0.51
α_{rc} [kW/m^2·°C]	5.72	5.74	5.75	5.74	5.74
Q_{cc}^{GS} [10^3 kJ]	50.7	114.1	39.72	59.2	67.6
Q_{fc}^{GS} [kJ]	63.6	97.5	53.4	70.2	84
D_a^{GS} [m^3_N/h]	98.5	93.3	48.6	66.1	158.1
Q_{aa}^{GS} [10^3 kJ]	3.3	3.1	1.61	2.2	5.23
W_a^{GS} [10^3 kJ]	54.1	117.3	41.4	61.5	72.91
Q_{cc}^{GD} [10^3 kJ]	155.8	199	157.1	153.78	164.3
Q_{fc}^{GD} [kJ]	195.7	166	206.4	178.3	199.5
D_a^{GD} [m^3_N/h]	186.4	158	153.6	167.8	248.8
Q_{aa}^{GD} [10^3 kJ]	6.1	5.2	5	5.45	8.2
W_a^{GD} [10^3 kJ]	162.1	204.3	162.3	159.4	172.7

The minimum load is, in this case, dynamic gap (no passengers), in which case Wu = 0, and is not suitable for developments. The average load is the load recorded during the analysis period [one year]. From the existing records is found that this is, in 2018: 42% (MERCEDES), 35% (VOLVO), 40% (SOLARIS) and 50% (ISUZU), respectively 40% (total BDE - OTL). The maximum load is considered to be 80% of BDE's total carrying capacity (seats and standing places). This value can be reached during peak hours. For the calculation of TEB components, it was taken into account that there are two categories:

- Practically independent load components (ΔWmec, W_{PTC});
- Components that increase, practically, proportional with the load, up to the nominal power/temperature (ΔWga, ΔWnm, ΔWrc, ΔWar).

Table 6. Results of real TEB of BDE, MERCEDES brand

Values **Characteristic values**	**Average load (2018)**		**Maximum load (peak time)**	
	[tep]	**[%]**	**[kep]**	**[%]**
A. Energy in[W_a]	323.5	100	143.4	100
B. Energy out [W_i]	323.5	100	143.4	100
1. Useful energy [W_u]	86.85	26.9	44.3	30.9
2. Loss [ΔW_p]	218.53	67.5	91.06	63.5
2.1 Heat dissipated by flue gases [ΔW_{ga}]	26.25	8.1	10.93	7.6
2.2 Heat dissipated by mechanical burns [ΔW_{nm}]	2.3	0.7	1.2	0.8
2.3 Radiation and convection losses [ΔW_{rc}]	1.43	0.4	0.9	0.6
2.4 Energy discharged with coolant [ΔW_{ar}]	90.32	27.9	37.3	26
2.5 Mechanical losses [ΔW_{mec}]	98.23	30.4	40.73	28.5
3. Own technological consumption [W_{CPT}]	18.12	5.6	8.03	5.6

Table 7. Results of real TEB of BDE, – OTL [2018]

Characteristic values	**Values**	
	[tep]	**[%]**
A. Energy in[W_a]	1156.7	100
B. Energy out [W_i]	1156.7	100
1. Useful energy [W_u]	312.31	27
2. Loss [ΔW_p]	796.97	68.9
2.1 Heat dissipated by flue gases [ΔW_{ga}]	109.9	9.5
2.2 Heat dissipated by mechanical burns [ΔW_{nm}]	11.57	1
2.3 Radiation and convection losses [ΔW_{rc}]	4.63	0.4
2.4 Energy discharged with coolant [ΔW_{ar}]	300.73	26
2.5 Mechanical losses [ΔW_{mec}]	370.14	32
3. Own technological consumption [W_{CPT}]	47.42	4.1

The values obtained for general EPI, during the testing period of the six BDE are shown in table 8, and the values obtained for 2018 are presented in table 9.

Table 8. Values of EPI for tested BDE's

Brand **Side No.** **EPI**	**MERCEDES**		**VOLVO**		**SOLARIS**	**ISUZU**
	115	134	146	76	150	89
η_b [%]	9.9	15.6	29.6	8.6	11.8	30
η_n [%]	3.4	9.1	25.8	4.8	5.6	27.4
c_n [%]	2822	1038	371.8	2039	1700	349
g_{IM} [%]	17.3	19.3	18.9	18.5	12.1	39.4
I_W [kep/leu]	0.031	0.032	0.033	0.039	0.032	0.035
P_W [lei/kep]	32.3	31.2	30.3	25.6	31.2	28.6
c_p^W [kep/km]	0.378	0.382	0.402	0.362	0.396	0.328
c_{sc}^W [gep/p·km]	81.2	70	94	74	90.6	104

Table 9. General EPI's BDE – OTL

EPI **Brand**	η_b [%]	η_n [%]	c_n [%]	g_{IM} [%]
MERCEDES	32.5	26.9	354	33.8
VOLVO	27.6	25.2	308	38.2
SOLARIS	27.3	25.3	375	27.7
ISUZU	30.5	30.3	313	21.6

In fig. 4 are the graphically representations of the values of "η_n" indicator for the significant brands from BDE fleet of OTL, and in the fig. 5 are shown the values of the indicator c_s^W.

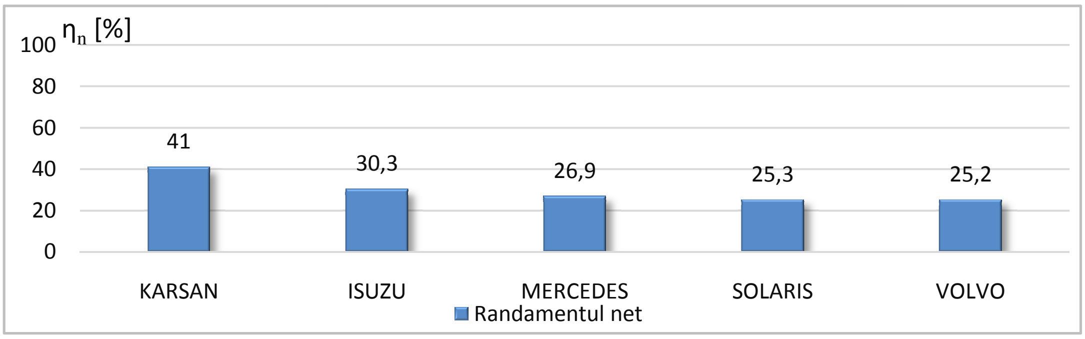

Fig. 4. The net yield of BDE's - OTL [year 2018]

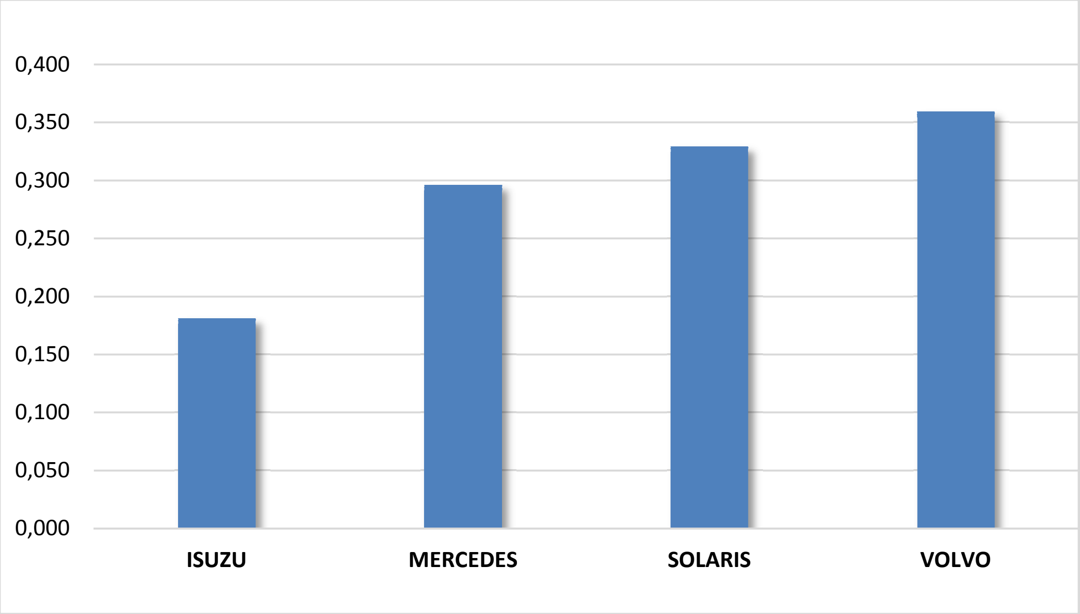

Fig. 5. Hierarchy of brands for BDE's of OTL, by value of c_s^W [year 2018].

In the table 10 are given the EPI values for the PTO - OTL fleet, during the analysis period.

Table 10. EPI values for BDE of OTL

Year EPI	2016	2017	2018
I_W [gep/Euro]	10.3	110.3	108.6
P_W [Euro/kep]	9.7	9.06	9.2
C_s^W [kep/km]	0.277	0.292	0.3
C_{sc}^W [gep/p·km]	63.1	67.6	66.48

Given the relationship between diesel consumption and the volume of exhaust gases, for the operating conditions of BDE - OTL it is possible to estimate the amount of pollutants emanating by the OTL car fleet, over time intervals (year, month, normal day, holiday, etc.). The results obtained for 2018 are shown in table 11.

Table 11. Estimate on the amount of pollutants emitted by the OTL fleet [year 2018]

Substance	CO_2	CO	NO	NO_2	NO_x	SO_2
M.U.	[t]	[t]	[t]	[t]	[t]	[t]
Value	3534.7	54.1	91.9	19.4	159.5	2.59

The coefficient of air excess (λ) has values in the range [3.2 ÷ 5.91] - much higher than the ideal value (λ = 1), corresponding to a complete combustion.

5. CONCLUSIONS

At the level of OTL company, can be concluded the conservation of the main energy performance indicators (I_W, P_W, c_s^W, c_{sc}^W), for the analyzed period, respectively, between 2016 and 2018. In 2018, there was a slight improvement of the indicators (I_W, P_W, c_{sc}^W) and a slight degradation of the c_s^W indicator, compared to 2017.

The indicator with the highest relevance for buses - the specific "complex" energy consumption (c_{sc}^W) has a much higher value for the whole OTL fleet than the EU average. Thus, in 2018, the value of c_{sc}^W for the OTL car fleet was 66.48 gep / p · km, and at EU level (for buses), the value indicated in [5, 22] is only 20 gep / p · km . The difference may be caused due the high specific consumption (l / km) and also to the too low load (p / km) of BDE - OTL. The records from OTL Databases does not contain references to the number of passengers carried with each BDE or to the entire group of BDE from each brand. For this reason, no comparisons can be made in terms of the values of the c_{sc}^W indicator between brands and between BDE belonging to the same brand.

The second indicator, in terms of relevance and share of use, in the case of buses, is the specific energy consumption (c_s^W). The values obtained for this EPI at the level of the OTL - PTF are much higher than those registered at EU level, respectively 0.3 kep / km - for the whole BDE - OTL (2018), compared to only 0.065 kep / km at EU level [22]. Comparing the ratios between the values of the two indicators (RO / EU), it can be seen that the main cause of the energy counterperformance of the OTL - PTF is the specific consumption (l / km) much higher than the EU average.

The records from the OTL database allow the calculation of the c_s^W indicator values for each BDE and also for the entire group of BDE within a brand. The values obtained allow hierarchyzation in terms of the values of EPI, as follows:

- In 2018, the BDE - OTL brands are ranked according to the values of the c_s^W indicator, as follows: KARSAN (best performing) - ISUZU - MERCEDES - SOLARIS - VOLVO - MAN (worst performing);
- Within each brand group, there are significant differences between samples, details are available in [21];
- There is no clear correlation between specific consumption and the age of BDE;

The tests performed on six BDE of the most used brands by OTL, allow us to establish: their short-term energy performance, the share of energy loss components and the flue gas content. In terms of energy, the tests showed the following:

- The short-term (momentary) energy performances of the tested BDE are in good correlation with the long-term energy performances (annual, monthly);
- The average load of the engines from BDE equipment - during the test period and during the normal operation period (long duration) - is relatively low, respectively: [12 ÷ 40]% - during the test period and [21 ÷ 39]% - during 2018. This finding reflects the fact that the engines equipped by BDE have an important power reserve, in the concrete operating conditions within OTL.;
- The share of energy loss components on BDE from the tested brands, operating under load, is in the ranges: mechanical losses on BDE [30 ÷ 34]% - of the energy consumed; thermal losses evacuated by the cooling agent by radiation and convection [25 ÷ 29]% - of the consumed energy; heat dissipated through the exhaust (flue gases + mechanical unburned) [10 ÷ 19]% - of energy consumed;
- The share of OCT is differentiated for the four brands analyzed, having in the interval [2016 - 2018], the values: 6.5% (MERCEDES), 6.2% (SOLARIS), 3.8% (VOLVO) and 2.6% (ISUZU).

In addition to energy performance, urban transport systems are characterized by the impact on the environment, the most important component of the environmental impact being the composition and quantity of substances that are emitted into the atmosphere through the exhaust. The buses used by PTO OTL have diesel engines that use diesel as fuel, which gives an advantage in terms of environmental impact, as they are less polluting, in principle, than thermal engines that use gasoline. Some of DBE – OTL are equipped with the "adblue" system - to reduce harmful substances such as NO and NO_2. The PTI tests performed by OTL measure the opacity of the exhaust gases. From the analysis bulletins of the six tested machines, it results that, for all, the opacity has the upper limit value (3 m^{-1}) [24].

In terms of CO and NO_x particulate emissions, the six BDE tested meet the Euro standard specified in the technical book. In terms of emission of carbon particles, none of the BDE tested meet the relevant Euro standard [25].

Based on the results obtained, summarized in the conclusions, measures have been identified to improve energy efficiency (concrete, feasible, applicable) and reduce negative environmental impacts on the environment, listed in table 12.

Table 12. Proposed measures to improve energy efficiency and improve environmental impact, OTL

No.	The proposed measure	Estimated energy savings [tep/an]	The necessary investment [thousand Euro]	Investment payback period [years]
0	1	2	3	4
Short and medium term measures [1 - 5 years]				
1	Decommissioning of old buses, with excessively high specific consumption	50.9	-	Administrative measure
2	Prompt and complete maintenance of BDE engines including, to increase combustion efficiency, reduce excess air and opacity [with priority to BDE with $\lambda \geq 3$ şi $O_p \geq 2,5\ m^{-1}$]	10.8	22.4	2
3	Prompt and efficient maintenance of BDE's mechanical transmission system (engine - wheels) with specific consumption above average	9.4	19.4	2
4	Optimization of the transport schedule and the work schedule of the buses, in correlation with their energy performance level	21.4	-	Administrative measure

Medium and long term measure [5-8 years], with large investments				
5	Acquisition of new, high-performance minibuses, in parallel with the decommissioning of the old ones			
	Diesel minibuses (20 pcs - until 2024)	110	2,908	15
	Electric minibuses (20 pcs - until 2024)	148	6,204	25

The information from [26, 27] was used to estimate investment costs. The decision on the implementation of measures 5 (a, b) must be based on both improving energy efficiency and improving environmental impact. It is recommended that measure 5b be applied in parallel with the construction of a photovoltaic park on the stations where OTL buses and trams are parked.

By applying the measures, listed in table 12, an optimized TEB is obtained (Table 13), characterized by IPE with the values in Table 14.

Table 13. Results on optimized TEB of BDE - OTL

Characteristic values	**Values**	
	[tep]	**[%]**
A. Energy in[W_a]	954.2	100
B. Energy out [W_i]	954.2	100
1. Useful energy [W_u]	312.31	32.7
2. Loss [ΔW_p]	594.47	62.3
2.1 Heat dissipated by flue gases [ΔW_{ga}]	81.1	8.5
2.2 Heat dissipated by mechanical burns [ΔW_{nm}]	7.97	0.8
2.3 Radiation and convection losses [ΔW_{rc}]	3.57	0.4
2.4 Energy discharged with coolant [ΔW_{ar}]	226.93	23.8
2.5 Mechanical losses [ΔW_{mec}]	274.9	28.8
3. Own technological consumption [W_{CPT}]	47.42	5

It was admitted that scale the service provided remains at level of the year 2018.

Table 14. General EPI values of BDE - OTL - optimized regime

Symbol EPI and M.U.	I_W [gep/leu]	P_W [lei/kep]	c_s^W [kep/km]	c_{sc}^W [gep/p·km]
EPI Values	64.7	15.5	0.178	39.3

By applying the measures listed in table 12, the environmental impact is improved, the amount of pollutants being reduced by about 18%.

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